# Using Stressor-Response Relationships to Derive Numeric Nutrient Criteria for Lakes and Reservoirs

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## Outline

- Background
- Stressor-response tasks
  - Define the endpoint and threshold.
  - Maximize the accuracy of the estimated relationship.
  - Account for and manage noisy data.



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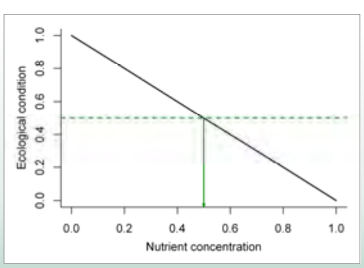
## What is a Stressor-Response Approach?

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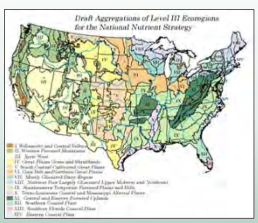
## Background

- Relationship between total phosphorus and chl *a* used to guide management of lakes (Dillon and Rigler, 1974).
- Stressor-response relationships described as an approach for deriving nutrient criteria for different waterbodies (EPA 2000).
- Guidance document on use of stressor-response released (2010).
- Re-evaluation of national recommended nutrient criteria for lakes and reservoirs underway (2014 – present).



## Ecoregional Nutrient Criteria

- Nutrient criteria recommendations published in 2000 – 2001 for lakes, reservoirs, rivers, and streams.
- U.S. classified into 14 nutrient ecoregions in which nutrient concentrations were expected to be similar.
- Nutrient criteria derived based on a reference distribution approach.
  - Criteria derived as the 25th percentile of all available nutrient data



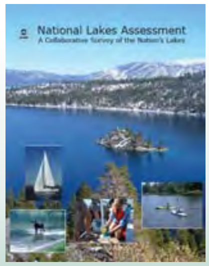



## Current National Nutrient Criteria Effort

- Re-evaluate recommended numeric nutrient criteria for lakes and reservoirs.
- Approach
  1. Define potential assessment endpoints and measures of exposure for aquatic life use, recreation, and drinking water source protection.
  2. Use national data to estimate stressor-response models that quantify relationships between nutrient concentrations and selected assessment endpoints.
  3. Derive recommended national numeric criterion values that protect three specific designated uses (public health and aquatic life).
  4. Provide approach for combining state data with national models.

## Data for National Nutrient Criteria

- National Lakes Assessment data
  - Survey data from 2007 and 2012 included
  - Extensive set of measurements collected at ~ 1800 randomly selected lakes.
  - Consistent protocols used to collect the same measurements from each of the lakes.

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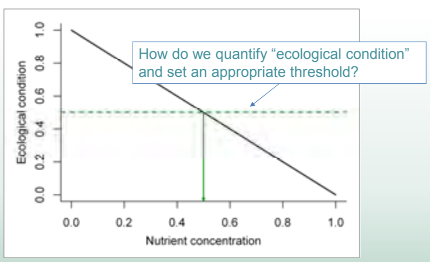
## Define the endpoint and threshold

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## Defining assessment endpoints

- Characteristics of useful assessment endpoints:
  - Responsive to nutrients
  - Quantitative
  - Linked directly to management goal
  - Data available
- Management goal:
  - "…water quality which provides for the protection and propagation of fish, shellfish, and wildlife and provides for recreation in and on the water…"
  - Three designated uses:
    - Aquatic life
    - Recreation
    - Drinking water source.
- Most sensitive use for each lake determines the final criterion value.

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## Defining assessment endpoints to protect aquatic life

- Management goal: "…protection and propagation of fish, shellfish and wildlife"
- Assessment endpoints: "…explicit expressions of the actual environmental value that is to be protected…"
- Selecting several endpoints ensures that aquatic life in different types of lakes is protected.
  - Zooplankton
  - Fish
  - Submerged aquatic plants

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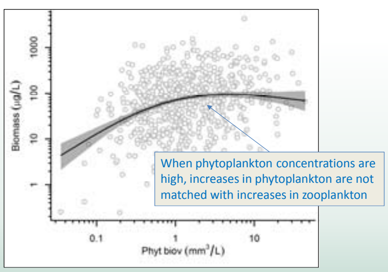
## Assessment endpoints: Zooplankton




In lakes with high concentrations of phytoplankton and nutrients, transfer of energy from primary productivity to higher trophic levels is less efficient.

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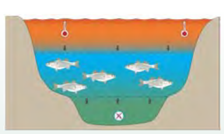
## Assessment endpoints: Fish

- Distribution of many fish species is limited by water temperature.
- In stratified lakes, depletion of oxygen below the thermocline can eliminate viable habitat for certain fish species.
- Potential endpoint: Sufficiently deep layer with dissolved oxygen > 4 mg/L below thermocline to allow fish to persist through the summer (US EPA 1986).



http://www.teachoceanscience.net/teaching_resources/education_modules/fish_and_physics/explore_trends/oxygen_and_water_temperature/

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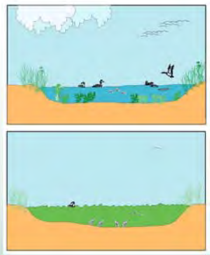
## Assessment endpoints: aquatic plants

- In shallow lakes, two stable states have been observed:
  - Aquatic plant dominated: clear water, diverse animal and plant communities
  - Phytoplankton dominated: turbid water, low diversity
- Potential endpoint: Sufficient coverage of submerged aquatic plants to maintain clear water.



Scheffer, M. 1999. Searching explanations of nature in the mirror world of math. Conservation Ecology **3**(2): 11. [online] URL: http://www.consecol.org/vol3/iss2/art11/

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## Exposure metrics for drinking water and recreational uses

- Drinking water source:
  - Microcystin concentration
  - Possible threshold: 0.3 µg/L (US EPA Health Advisory for children, 2015)
  - Based on a variety of health effects
- Recreation:
  - Microcystin concentration
  - Possible threshold under development.
    - Incidental ingestion during recreation

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## Assessment endpoints: Summary

- Characteristics of useful assessment endpoints:
  - Responsive to nutrients
  - Quantitative
  - Linked directly to management goal
  - Data available
- National scale of 304(a) limited by data availability
  - Additional endpoints one might consider at local scales:
    - Fish abundance
    - Reference site biological characteristics
    - User perception surveys
      - Water transparency (e.g., Secchi depth)

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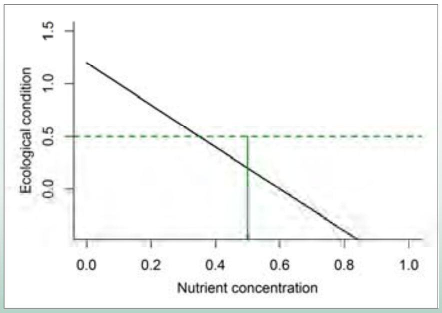
## Accuracy of Stressor-Response Relationships

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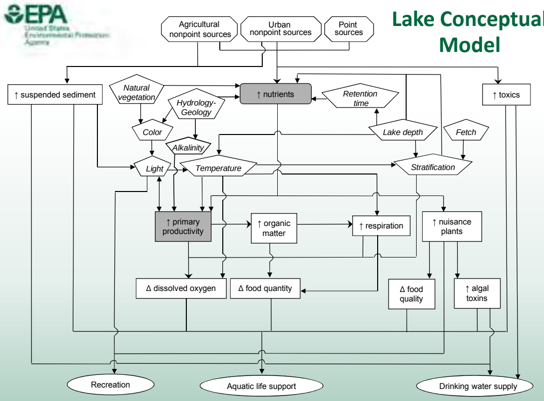


## Lake Conceptual Model

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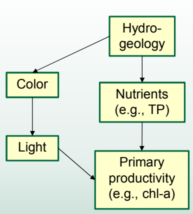
## Accuracy: Are All Relevant Covariates Considered?

- To identify potential confounding variables, select variables along each “backdoor” path linking the stressor with the response variable.
- Color can directly influence light availability and primary productivity, and is influenced by the hydrogeology of the lake watershed.

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## Accuracy: Are All Relevant Covariates Considered?

How strongly are covariates correlated with the stressor variable?

| | All data | Within classes | |
|---|---|---|---|
| | | Average | Range |
| log (conductivity) | 0.36 | 0.14 | 0.06 – 0.23 |
| log (color) | 0.26 | 0.15 | 0.01 – 0.35 |

Correlation coefficients between TN and different covariates

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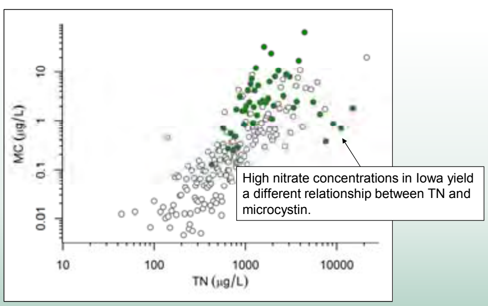
## Test Relationships Using Different Datasets

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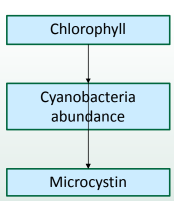
## Improving accuracy

Explicit models for different steps in the causal chain can improve accuracy of estimated relationships.

Bayesian network models provide framework for modeling relationships between many different variables.

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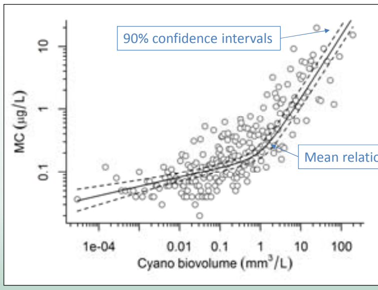
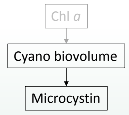
## Cyanobacteria biovolume and MC

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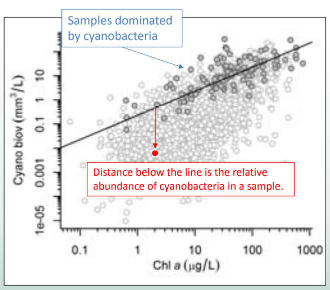
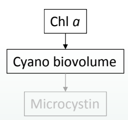
## Chl *a* and cyanobacteria biovolume




When samples are dominated by cyanobacteria, the average chl *a* content of each cyanobacteria cell defines the relationship between chl *a* and cyano biovolume:

Cyano = k × chl *a*

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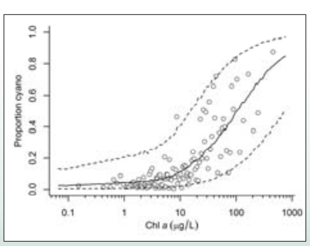
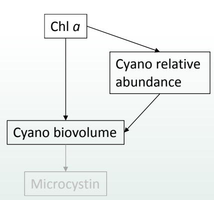
## Chl *a* and cyanobacteria relative abundance




Cyanobacteria relative abundance increases with chl *a*.

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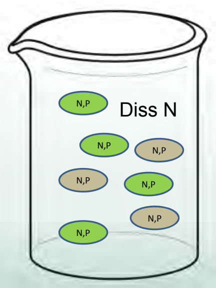
## Modeling total nutrient concentrations

$$\log(chl\ a) = d_1 + d_2\log(TN)$$

$$TN = k_1 chl\ a + k_2 sed + N_{diss}$$

$$\log(TN) = \log(k_1 chl\ a + k_2 sed + N_{diss})$$



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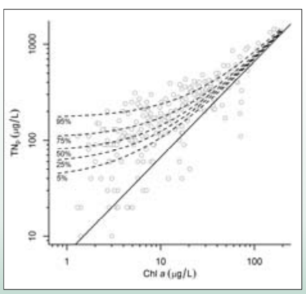
## TN and chlorophyll *a*




Weekly measurements from 15 Missouri reservoirs.

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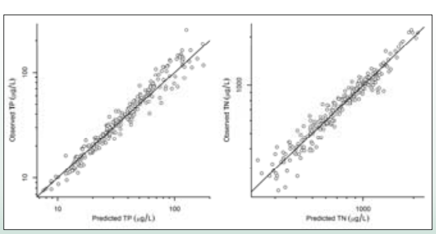
## Predictive performance of TP and TN models




Models for TN and TP predicted observed TN and TP accurately and precisely.

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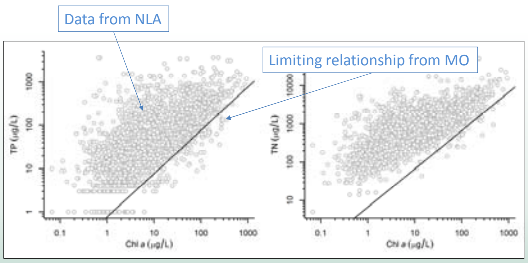
## Model comparison




Limiting relationships estimated in MO seem applicable nationally.

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## Accuracy: Is the Estimated Relationship Consistent With Other Estimates?

- How similar are models computed within a waterbody and models computed across different waterbodies?
- How similar is the estimated model to other models documented in the literature?
- Does the inclusion of covariates in the model substantially alter the estimated stressor-response relationship?

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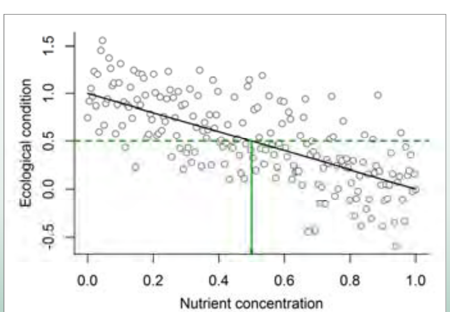
## Accounting for Noisy Data (Model Precision)

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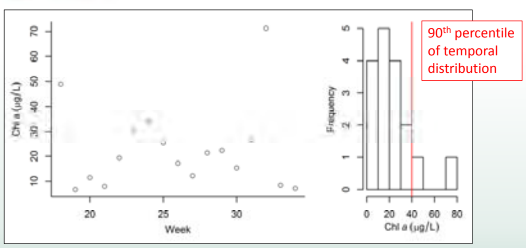
## Accounting for Residual Variability

- Three components of residual variability
  - Temporal variability
  - Sampling variability
  - Spatial variability



## Temporal Variability



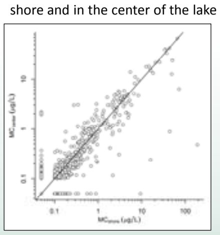

If we know how much conditions vary in time, we can specify criteria based on allowable exceedance probability.

Example: Maintain chl *a* below 20 µg/L for 90% of the days in the summer.



## Sampling Variability

Comparison of microcystin at the shore and in the center of the lake



Lake St. Clair

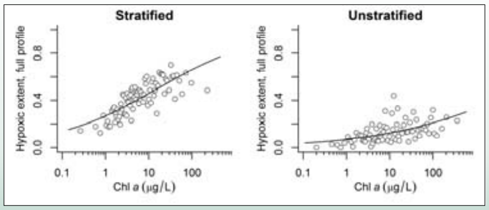
Image: Joshua Stevens/NASA Earth Observatory

Sampling variability includes differences among samples collected at different locations in a lake at the same time. If we know the magnitude of the sampling variability, we can specify criteria that account for the range of possible measurements.

Example: Maintain microcystin below some threshold over 90% of the lake surface.

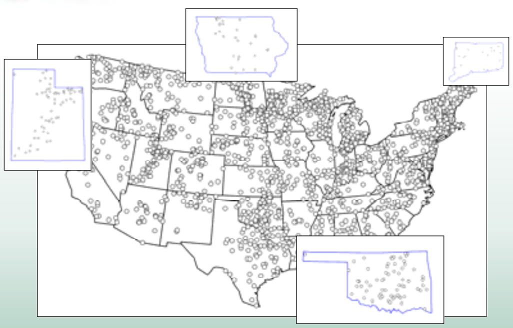
## Spatial Variability

Differences in stressor-response relationships among water bodies can often be taken into account by classification.





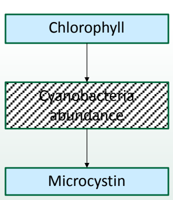

## State-specific Models



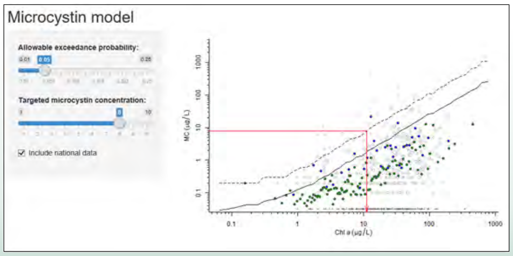


## Iowa Case Study

- Chl *a,* cyanobacteria abundance, and microcystin data were available in Iowa.
- Iowa cyanobacterial abundance data were biased and could not be used.
- National and Iowa data were used to estimate chl *a* - MC relationship.



## Iowa Case Study

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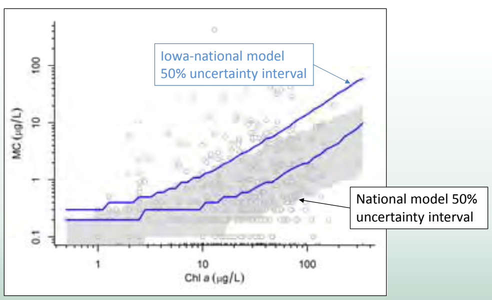
## Iowa Case Study




Shaded area and blue lines enclose the uncertainty interval for the 90th percentile of the predicted MC concentration.

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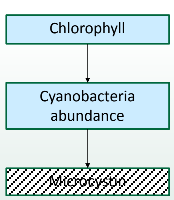
## Utah case study

- Only chl *a* and cyanobacteria abundance data were available in Utah.
- National and Utah data were used to estimate chl *a*/cyano relationship.
- Only national data were used to estimate cyano – microcystin relationship.

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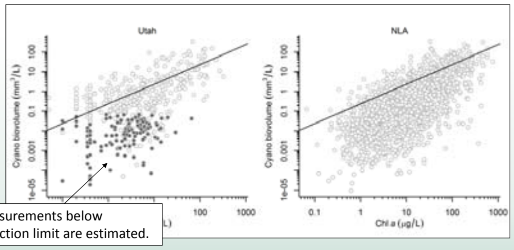
## Utah Case Study




Measurements below detection limit are estimated.

Comparison of Utah and NLA cyanobacteria data indicated that higher detection limits occurred in the Utah data.

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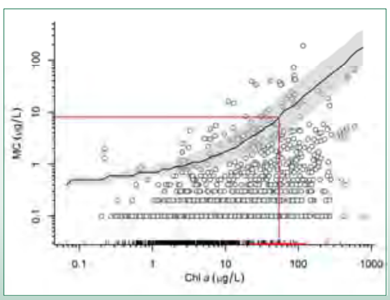
## Utah Case Study

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## Lessons Learned

- Ecological endpoints:
  - Methodical process for evaluating available data and connection to designated uses yields appropriate endpoints.
- Stressor-response relationship accuracy:
  - Examine conceptual model.
  - Test with validation data.
- Stressor-response relationship precision:
  - Estimate temporal, sampling, and spatial components of variability to improve decision making.
  - Classification can improve precision while maintaining model interpretability.
  - Combining state and national data can improve model performance.

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## Next Steps for National Nutrient Criteria

- Complete documentation and review of underlying science.
  - Journal manuscripts.
  - Internal review.
- Public outreach and communication.
- Propose revised national numeric nutrient criteria for lakes.

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Title: Numeric Nutrient Criteria: Duration and Frequency

Presenter and discussion moderator: Jacques L. Oliver, U.S. EPA, Office of Water, Office of Science and Technology

Format: 10 min. presentation (ppt), 20 min. facilitated discussion

Anticipated outcomes:

1. Awareness on the difference between the duration and frequency of nutrient criteria that confer protection of designated uses from the duration and frequency associated with representative monitoring and data synthesis for regulatory assessments,
2. Understanding the technical approaches used to estimate nutrient criteria duration and frequency, and
3. Develop action items that advance awareness, understanding, and quantitative estimation of nutrient criteria duration and frequency.

Abstract

Water quality criteria are comprised of three elements: magnitude (how much), duration of exposure (how long), and frequency of exposure (how often). These elements of nutrient criteria may vary depending on their expression in regulation (narrative vs. numeric) or the scales of the assessment endpoints and measures of effect used during nutrient criteria development (e.g., seagrass light requirements, cyanobacterial abundance, dissolved oxygen concentration, etc.). Duration and frequency are key components to ensuring the protection of designated uses because they provide a temporal dimension to water quality expectations that, in turn, influences when water quality is monitored and assessed for Clean Water Act compliance purposes. Due to their close association with water quality monitoring activities, *nutrient criteria* duration and frequency are often used synonymously with the duration and frequency of nutrient *environmental monitoring and sampling*[1]. Similarly, *nutrient criteria* duration and frequency are sometimes used synonymously with the duration and frequency associated with nutrient *water quality assessments*[2]. Examples differentiating *nutrient criteria* duration and frequency from the duration and frequency of nutrient *environmental sampling* and *water quality assessments* will be presented. Technical approaches to estimating nutrient criteria duration and frequency will be also presented, followed by open discussion and participant-driven action item development.

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[1] For example, how long and how frequently should we sample the stream in order to generate representative data from which we can detect compliance/non-compliance with water quality criteria?

[2] For example, over what period of time do we evaluate nutrient water quality data such that conclusions can be made regarding attainment/impairment pursuant to CWA 303(d)?

# Numeric Nutrient Criteria: Duration and Frequency

Jacques L. Oliver, U.S. EPA, Office of Water, Office of Science and Technology
Eastern Numeric Nutrient Criteria Workshop
Atlanta, Georgia
April 24 – 26, 2018

## Goals for this session

1. Clarifying nutrient water quality criteria duration and frequency
2. Highlighting approaches and techniques that estimate them
3. Discussion, feedback, and action items



## Distinguishing criteria duration and frequency

| Criteria | WQ Monitoring/Sampling | Assessment Period |
|---|---|---|
| Protective length of time and frequency of *exposure* to a pollutant or pollutant parameter magnitude | Length of time and frequency of *observations* needed to detect exceedance of the criteria | Length of time and frequency of *concluding* exceedance of the criteria |

| Nutrient Criteria Duration/Frequency | Criteria Monitoring/Sampling Period | Criteria Assessment Period |
|---|---|---|
| Surface* median** concentration of 1 mg/L over the **growing season, with no excursions in more than one year** | Monitor over the growing season (90 – 120 days), Sample* throughout the season | One 303(d) assessment every two years, Two annual index periods |
| Duration: growing season<br>Frequency: no excursions in more than one year | *Surface sampling | **Median: data handling |

## Assessment endpoints and duration/frequency

Management goal: Recreational Use (swimming in temperate lakes)
Assessment endpoint: Frequent cyanobacterial *blooms* (implies peak biomass)
Measure of effect: Chl-a concentration
Magnitude: A surface median chl-a concentration of 20 µg/L…
Duration: …lasting no more than two weeks during the growing season…
Frequency: …with no more than one excursion per growing season.

| Nutrient Criteria Duration/Frequency | Criteria Monitoring/Sampling Period | Criteria Assessment Period |
|---|---|---|
| Surface* median** chl-a concentration of 20 µg/L over **two weeks within the growing season**, with **no more than one excursion per season** | Monitor over the growing season, Sample* over two week periods, Random + targeted sampling | One 303(d) assessment every two years, Two growing seasons |
| | *Surface sampling | **Median: data handling |

## Assessment endpoints and duration/frequency

Management goal: Aquatic life (warm, subtropical estuary)
Assessment endpoint: Seagrasses (implies nutrient-driven algal turbidity)
Measure of effect: Water clarity (light attenuation, Secchi disk depth)
Magnitude: Water clarity in nearshore waters (up to 3 m depth) expressed as a median Secchi disk depth of 1.2 m…
Duration: …over one year…
Frequency: …with no more than one excursion over two years.

| Nutrient Criteria Duration/Frequency | Criteria Monitoring/Sampling Period | Criteria Assessment Period |
|---|---|---|
| Nearshore* median** Secchi disk depth of 1.2 m over **one year**, with **no more than one excursion over two years** | Monitor over the year, Sample* over the year, Random + targeted sampling | One 303(d) assessment every two years, Two, one-year periods |
| | *Nearshore sampling | **Median: data handling |



## Estimating duration and frequency

Toxic pollutants

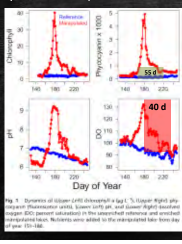
- Controlled laboratory experiments (removes confounding variables)
  - Project across many waterbody types
- Dose-response (gradient)
- Lethal effects (hours)
- Frequency: Recovery time (months+)

Nutrient pollution

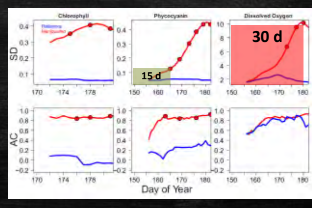
- Field monitoring of ambient surface WQ (includes confounding variables)
  - Reflects waterbody-specific conditions
- Correlations, not dose-response
- Myriad sub-lethal effects (days – months)
- Frequency: Recovery time (weeks+)

## Estimating nutrient criteria magnitude and duration:
## An approach inspired by the experimental work of M. Pace et al., 2017, *PNAS*

Recovery time after exposure to a nutrient supply




Exposure to a nutrient supply over time




## Goals for this session

1. Clarifying <u>nutrient water quality criteria</u> duration and frequency
   - Take home: Be careful not to substitute the temporal scales of what is protective with the temporal scales of monitoring and assessment
   - Take home: For nutrient pollution, the assessment endpoint can influence the temporal scales of criteria duration and frequency (and, in turn, the temporal scales of monitoring and assessment)
2. Highlighting approaches and techniques that estimate them
   - Take home: Apply appropriate time-scales, pollutant gradients, and a means to account for confounding variables
3. Discussion, feedback, and action items

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## Discussion, feedback, and action items

Discussion

- Clarifying questions and comments

Feedback

- What techniques have you used to estimate duration and frequency?
- What scientific information do you see as foundational to estimating duration and frequency? Examples: physiological, metabolic, life histories
- What aspects of narrative nutrient criteria contribute to estimating duration and frequency?

Action items

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WYOMING DEPARTMENT OF ENVIRONMENTAL QUALITY

# *Using shifts in phytoplankton communities to derive combined nutrient criteria for lakes*

Eric Hargett

Western Numeric Nutrient Criteria Workshop
May 1 - 3, 2018
San Francisco, California

## Presentation Outline

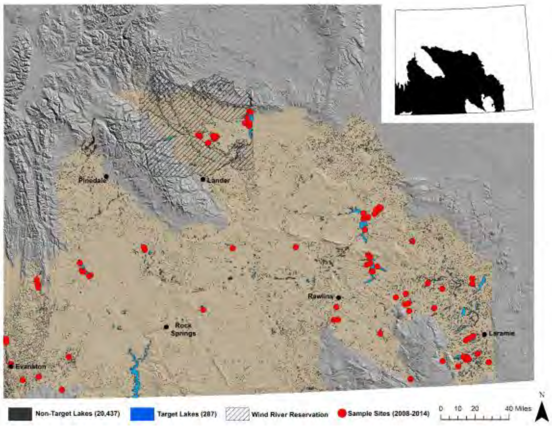
WYOMING DEPARTMENT OF ENVIRONMENTAL QUALITY

- Approach
- Scope / Data
- Criteria Development Process
- Status

## Approach

WYOMING DEPARTMENT OF ENVIRONMENTAL QUALITY

- Regional-based *combined* criteria (TP, TN, Chl-a) for protection of aquatic life in perennial lakes within the Wyoming Basin level III ecoregion
- Stressor-response methodology
  - Derive biological threshold concentrations (BTCs) - TP/TN concentrations that correspond to significant changes in the structure or function of phytoplankton
  - Identify BTCs that corresponded to ‘adverse alterations’ in the phytoplankton community and set TP/TN criteria to prevent such alterations from occurring
  - Chl-a criteria derived from empirical relationships of TP/TN and Chl-a
  - Criteria corroborated with scientific literature, trophic state indices and other adopted state lake nutrient criteria




## Scope / Data

WYOMING DEPARTMENT OF ENVIRONMENTAL QUALITY

- Perennial lakes (all reservoirs) – 200 total
- >10 acre surface area and maximum summer pool depth >1.0 meter and <30.0 meter
- Data used to develop criteria
  - Probabilistic monitoring design based on level IV and size class
  - Collections occurred during 2008-2014
  - Data obtained from 67 monitoring sites representing 52 lakes (26% of the realized target population of 200 lakes)
  - 4,500 chemical, physical and chl-a that equated to 321 samples
  - 259 phytoplankton samples
  - Represented three seasons from June 1 to October 15

## Scope / Data

- Typical lake characteristics
  - Alkaline (~200 mg/L CaCO3)
  - Cold to cool-water lakes (20-24°C)
  - Maximum depth (5-8 meters)
  - Elevation (~7,000 ft)
  - Generally holomictic with weak to no stratification
  - Support primarily cold-water fisheries
  - Moderate turbidity year-round (high fetch)
  - Many publically accessible

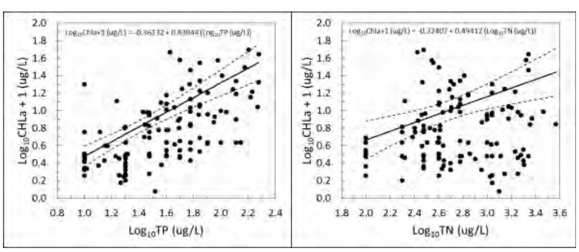
- Criteria developed for the growing season (July 15 – September 30)

## Lake Grouping

- Cluster analyses (UPGMA) and Non-metric multidimensional scaling (NMDS)
- Four groups identified
- Significant linear relationships between TP, TN and Chl-a for each group though statistically similar between groups (ANCOVA)

- Combined into a single Wyoming Basin lake group
- Significant linear relationships between TP, TN and Chl-a for Wyoming Basin lake group

## Responses of Chl-a to Nutrients




- Linear Quantile Regression (LQR) at the 75th quantile

## Biological Threshold Concentrations (BTCs)

WYOMING DEPARTMENT OF ENVIRONMENTAL QUALITY

1 - Additive Quantile Regression Smoothing (AQRS)

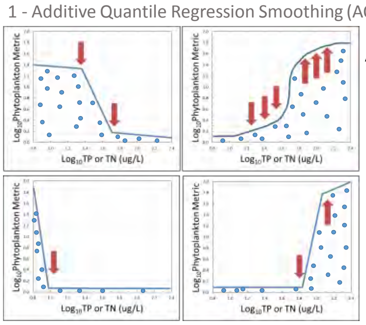
2 - Non-Parametric Changepoint Analyses(nCPA)

3 - Threshold Indicator Taxa ANalysis (TITAN)

## Biological Threshold Concentrations (BTCs)

1 - Additive Quantile Regression Smoothing (AQRS)

WYOMING DEPARTMENT OF ENVIRONMENTAL QUALITY



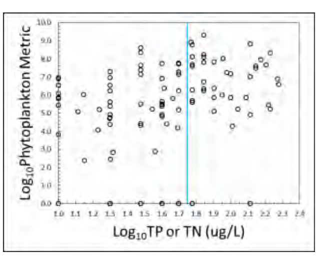

Adapted from Stevenson et al. (2008)

- Identify BTCs for TP and TN at changepoints along response curves (75th quantile) for 124 phytoplankton metrics

## Biological Threshold Concentrations (BTCs)

2 - Non-Parametric Changepoint Analyses(nCPA)

WYOMING DEPARTMENT OF ENVIRONMENTAL QUALITY



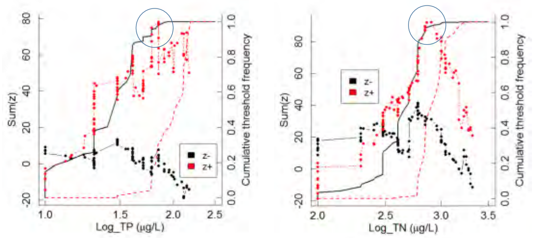

- Identify BTCs for TP and TN that correspond with the first split or the greatest change in responses among 124 phytoplankton metrics

## Biological Threshold Concentrations (BTCs)

3 - Threshold Indicator Taxa ANalysis (TITAN)

Community-level changepoint

WYOMING DEPARTMENT OF ENVIRONMENTAL QUALITY



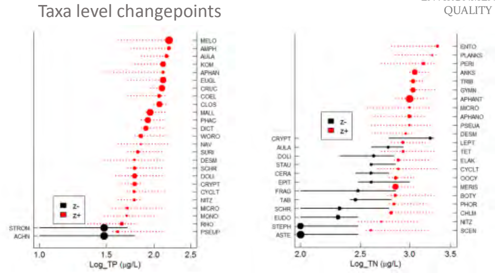

- Identify BTCs as the peaks of the maximum sum of tolerance scores for those taxa that are significant 'increasers' or 'decreasers' along the TP gradient

## Biological Threshold Concentrations (BTCs)

3 - Threshold Indicator Taxa ANalysis (TITAN)

Taxa level changepoints

WYOMING DEPARTMENT OF ENVIRONMENTAL QUALITY




- Identify taxon-specific BTCs for only pure (always respond in same direction) taxa that had significant and strong (high Z score) responses to nutrients

## Biological Threshold Concentrations (BTCs)

WYOMING DEPARTMENT OF ENVIRONMENTAL QUALITY

24 BTCs for TP (30 – 130 ug/L)

| Phytoplankton BTCs | Metric Type | Nutrient (µg/L) | AQRS | nCPA | TITAN* |
|---|---|---|---|---|---|
| Log Aphanizominon Density (cells/L) | Blue-green algae genus | TP | | | 130 |
| Log Chlorococcales Density (cells/L) | Green algae order | TP | 50 | | |
| Log Coscinodiscophyceae Density (cells/L) | Green algae class | TP | 40 | | |
| Log Cryptomonas Density (cells/L) | Cryptomonad algae genus | TP | | | 60 |
| Log Cyanophyceae Density (cells/L) | Blue-green algae class | TP | 70 | 50 | |
| Log Cyclotella Density (cells/L) | Diatom algae genus | TP | 60 | | 60 |
| Log Dolichospermum Density (cells/L) | Blue-green algae genus | TP | | | 60 |
| Log Euglena Density (cells/L) | Euglenoid algae genus | TP | | | 130 |
| Log Euglenophyta Density (cells/L) | Euglenoid algae family | TP | 70 | | |
| Log Microcystis Density (cells/L) | Blue-green algae genus | TP | | | 50 |
| Log Monoraphidium Density (cells/L) | Green algae genus | TP | | | 50 |
| Log Navicula Density (cells/L) | Diatom algae genus | TP | | | 70 |
| Log Nitzschia Density (cells/L) | Diatom algae genus | TP | | | 60 |
| Log Nostocales Density (cells/L) | Blue-green algae order | TP | 70 | 65 | |
| Log Palmer Metric (cells/L) | Nutrient Pollution Index | TP | 30 / 60 | | |
| Log Rawson Metric (cells/L) | Nutrient Pollution Index | TP | | 60 | |
| Log Rhodomonas Metric (cells/L) | Cryptomonad algae genus | TP | | | 44 |
| Log Schroederia Metric (cells/L) | Green algae genus | TP | | | 60 |
| Log Surirella Density (cells/L) | Diatom algae genus | TP | | 65 | 65 |
| Log Taylor Metric (cells/L) | Nutrient Pollution Index | TP | 60 | 50 | |
| TITAN sum(z+) | Phytoplantkon community | TP | | | 70 |

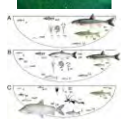
## Biological Threshold Concentrations (BTCs)

15 BTCs for TN (260 – 1449 ug/L)

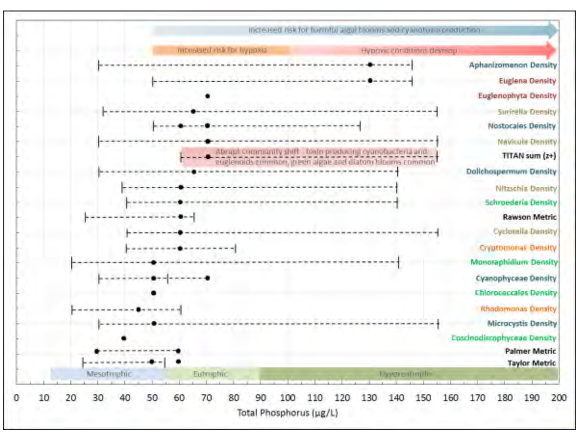
| Phytoplankton BTCs | Metric Type | Nutrient (µg/L) | AQRS | nCPA | TITAN* |
|---|---|---|---|---|---|
| Log Aphanocapsa Density (cells/L) | Blue-green algal genus | TN | | 700 | 1000 |
| Log Aphanothece Density (cells/L) | Blue-green algal genus | TN | | | 1000 |
| Log Asterionella Density (cells/L) | Diatom algae genus | TN | | 260 | 100 |
| Log Chlamydomonas Density (cells/L) | Green algae genus | TN | | 674 | 632 |
| Log Fragilaria Density (cells/L) | Diatom algae genus | TN | | 1100 | 300 |
| Log Gymnodinium Density (cells/L) | Dinoflagellate algal genus | TN | | | 1100 |
| Log Merismopedia (cells/L) | Blue-green algal genus | TN | | 905 | 700 |
| Log Microcystis Density (cells/L) | Blue-green algae genus | TN | | | 1000 |
| Log Peridinium (cells/L) | Dinoflagellate algal genus | TN | | | 1449 |
| TITAN sum(z+) | Phytoplantkon community | TN | | | 849 |

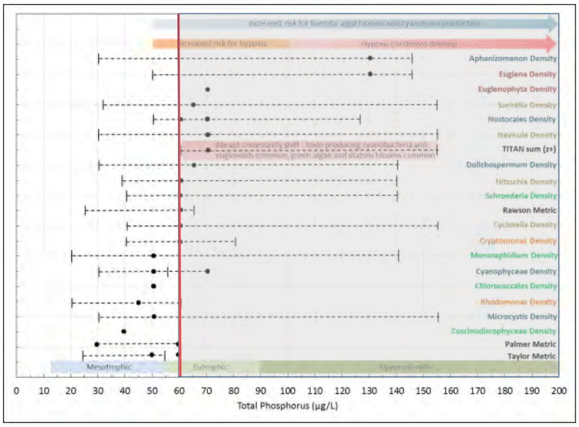
## Which BTCs correspond to 'Adverse Change'?

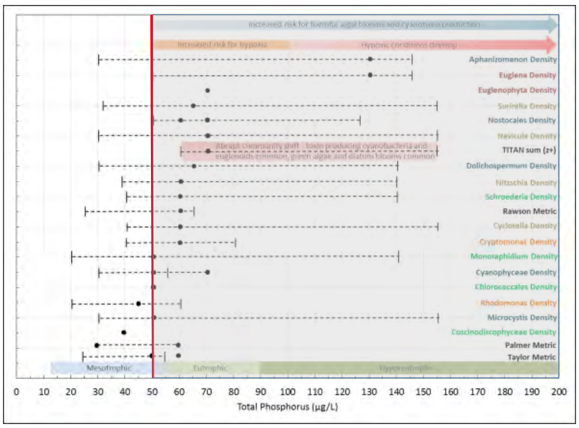
BTCs = Adverse ? =

- Taxa autecological information
  - Cyanobacteria that form HABs
  - Toxin producing cyanobacteria and dinoflagellates
  - Known effects of toxins to aquatic life
  - Eutrophic/hyper-eutrophic indicators
  - Hypoxic indicators
  - Overall phytoplankton community shift
  - Elevated densities that correspond to nuisance blooms

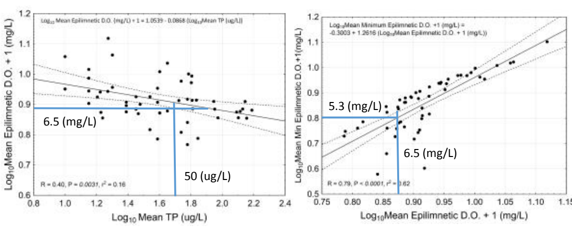




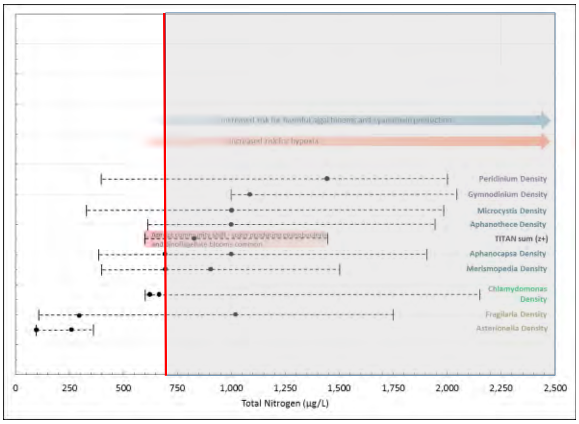




## Risk of hypoxia…
## Epilimnetic D.O. vs. TP

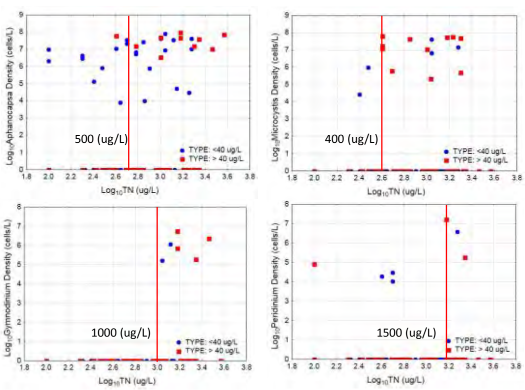
WYOMING DEPARTMENT OF ENVIRONMENTAL QUALITY




Cold-water fisheries: 6.5 mg/L (7 day mean) and 5.0 mg/L (1 day minimum)




## Is managing for TP enough?



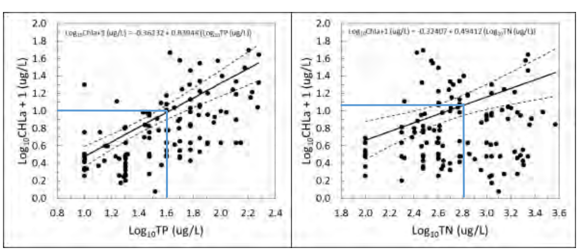

## Deriving Combined Criterion

WYOMING DEPARTMENT OF ENVIRONMENTAL QUALITY

TP ~ 40 µg/L
Chla ~ 9 µg/L

TN ~ 650 ug/L
Chla ~ 11 ug/L

Not to exceed maximums: ~60 ug/L TP, ~850 ug/L TN



## Timeline

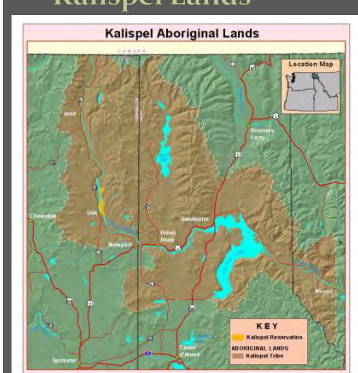
- Spring 2017 - Draft Technical support document for combined numeric nutrient criteria for Wyoming Basin lake
- Spring 2018 – Received reviews from three recognized external peer-reviewers with charge questions
- Summer/Fall 2018 - Evaluate external peer-reviews and revise criteria as needed
- Fall/Winter 2018 - Disseminate to WY Nutrient Workgroup and EPA for informal review

# Phosphorus Control
# in the
# Oligotrophic Pend Oreille Basin

Ken Merrill, Kalispel Natural Resources
May 2018

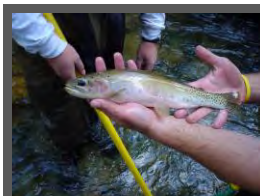
## Pend Oreille River Nutrient Considerations


## Kalispel Lands




- Kalispel Adjudicated Aboriginal Boundary
  - NE Washington, Idaho and Western Montana
  - Over 2.3 million acres
- Reservation
  - NE Washington
  - 4,750 acres
  - 1,900 additional acres in Trust status since 1997 (with cons. easements)

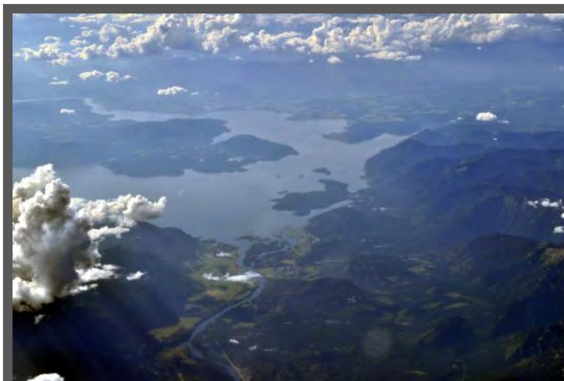

http://iafi.org/

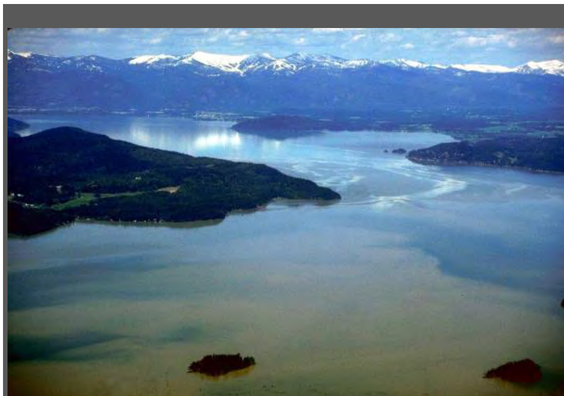


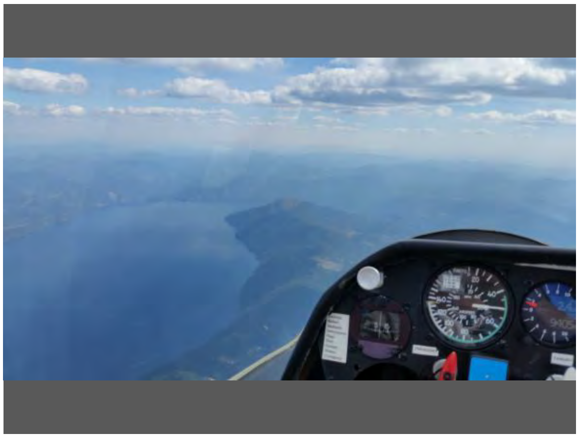

## Pend Oreille Basin Westslope Cutthroat Trout and Bull Trout ("Salmon Trout")

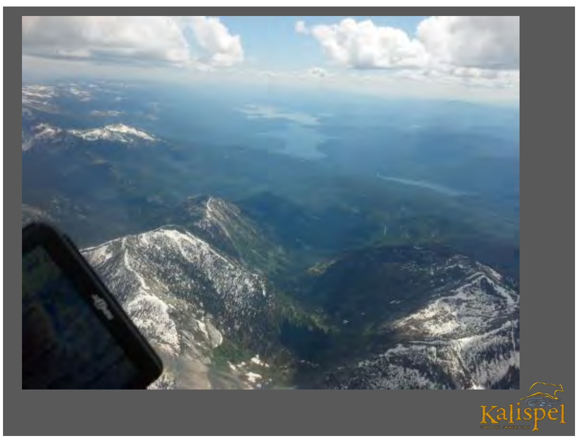
### Cold-Clean-Complex-Connected Habitat

## Connecting Habitat for Adfluvial Salmonids







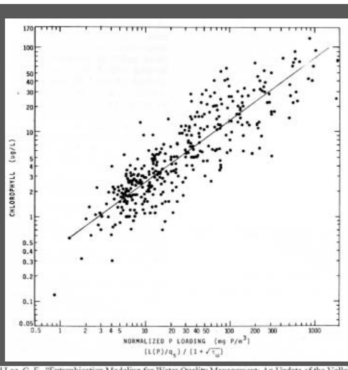

Kalispel


Kalispel

## Nutrient Targets in Clark Fork-Pend Oreille

- Tri-State Water Quality Council (>$1 million federal)
- MT-ID MOA - Lake Pend Oreille open water TP target 7.3 ug/L (area-weighted euphotic zone geometric mean)
- The MT Clark Fork River Voluntary Nutrient Reduction Program 1998-2008
  - **Two actions >85% TP reduction from wastewater discharges in MT**
    1) **Missoula, MT WWTP nutrient removal**
    2) **Frenchtown, MT Pulp Mill closure (Dec-09)**
- ID TMDL - Lake Pend Oreille near-shore 9 ug/L avg – **12** ug/L instantaneous
- Pend Oreille R. arm listed -then delisted for phosphorus in ID downstream of Sandpoint WWTP
- Pend Oreille River listed -then delisted for pH violations in WA
- Kalispel TP Criteria - 10 µg/L as P, 30-day avg, April–Oct

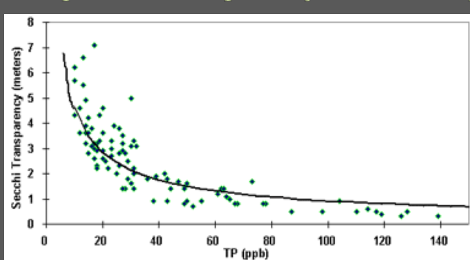
Kalispel




Jones, R. A. and Lee, G. F., "Eutrophication Modeling for Water Quality Management: An Update of the Vollenweider-OECD Model," World Health Organization's Water Quality Bulletin 11:67-174, 118 (1986).
http://www.gfredlee.com/Nutrients/voll_oecd.pdf

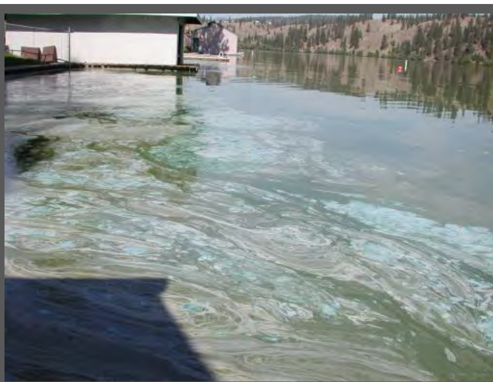
Kalispel

## Phosphorus -Transparency - Productivity




From: Lake Access, Minnesota EMPACT Project

Kalispel



## NUTRIENT CRITERIA DEVELOPMENT IN WASHINGTON STATE (2004):

### Phosphorus - Triggers for Riverine Systems

- Changes to water quality due to excess nutrients are expressed first through the impacts to other more sensitive water quality criteria
- Before nuisance levels of algal growth occur and aesthetics are noticeably impaired, streams and rivers will have violations of the state's dissolved oxygen, pH, and turbidity criteria
- These criteria, which are designed to provide full support to sensitive aquatic life communities, have been found to be more reliable indicators of trophic health

Kalispel

## NUTRIENT CRITERIA DEVELOPMENT IN WASHINGTON STATE (2004):

### Phosphorus - Triggers for Riverine Systems

- ...............The **second key indirect indicator of river eutrophication is the state's pH criteria**. **Excess nutrients in the state are identified by increasing trends in pH concentrations and by exceedances of the upper pH levels established for the water bodies. After such problems are identified, the criteria serve as targets for restoration and clean up that directly incorporate the causal effect of nutrients**

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## NUTRIENT CRITERIA DEVELOPMENT IN WASHINGTON STATE (2004):

### Phosphorus - Triggers for Riverine Systems

- Violations of these other trigger criteria, result in 303(d) listings and comprehensive water body-specific studies that are used to establish clean up requirements.
- These system-wide remedies examine the role of nutrients as well as other key facilitating parameters such as flows, temperature, and BOD when setting requirements for returning full health to the water body

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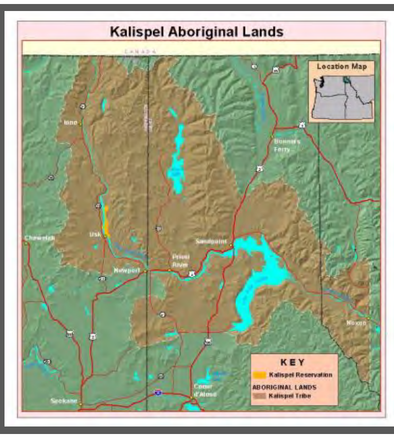


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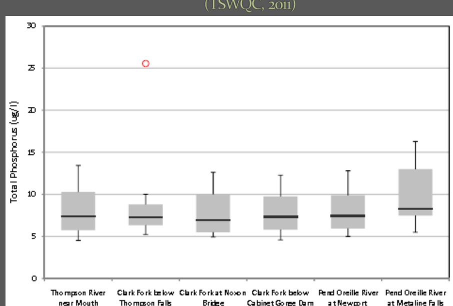
## Clark Fork – Pend Oreille 2010 TP Comparison

(TSWQC, 2011)

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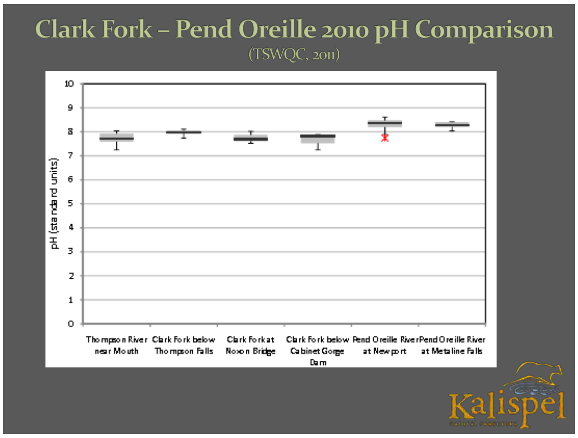
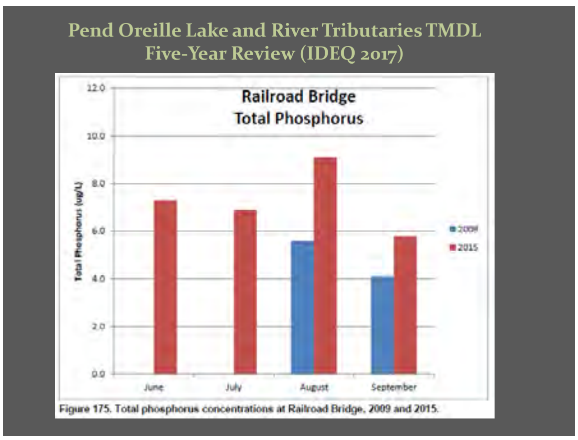
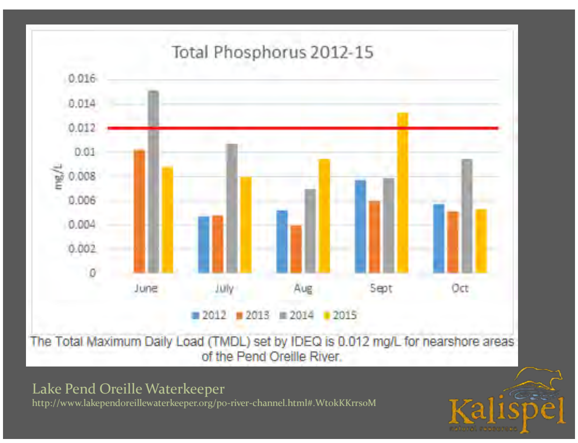
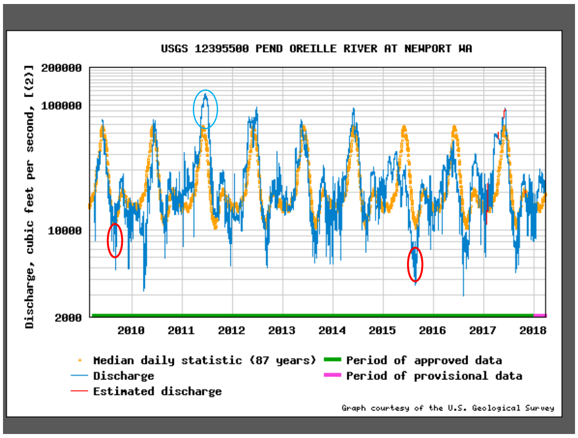
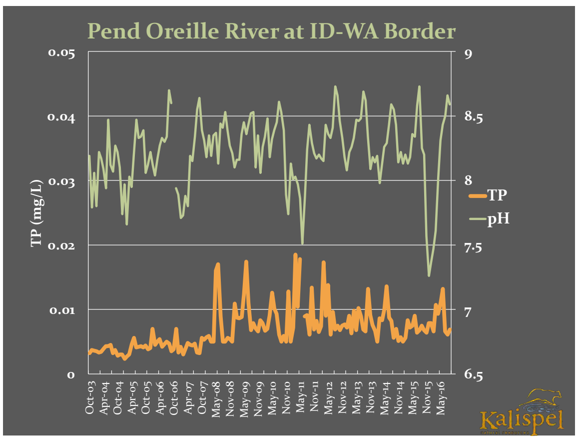
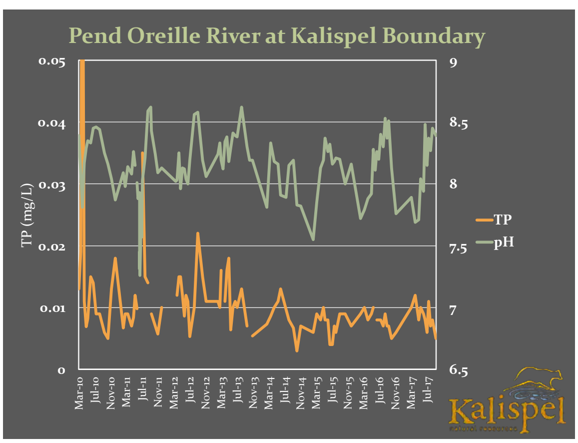

Clark Fork – Pend Oreille 2010 pH Comparison
(TSWQC, 2011)
pH (standard units)
10
9
8
7
6
5
4
3
2
1
0
Thompson River near Mouth
Clark Fork below Thompson Falls
Clark Fork at Noxon Bridge
Clark Fork below Cabinet Gorge Dam
Pend Oreille River at Newport
Pend Oreille River at Metaline Falls
Kalispel


Pend Oreille Lake and River Tributaries TMDL
Five-Year Review (IDEQ 2017)
Railroad Bridge
Total Phosphorus
Total Phosphorus (ug/L)
12.0
10.0
8.0
6.0
4.0
2.0
0.0
June
July
August
September
2009
2015
Figure 175. Total phosphorus concentrations at Railroad Bridge, 2009 and 2015.


Total Phosphorus 2012-15
mg/L
0.016
0.014
0.012
0.01
0.008
0.006
0.004
0.002
0
June
July
Aug
Sept
Oct
2012
2013
2014
2015
The Total Maximum Daily Load (TMDL) set by IDEQ is 0.012 mg/L for nearshore areas of the Pend Oreille River.
Lake Pend Oreille Waterkeeper
http://www.lakependoreillewaterkeeper.org/po-river-channel.html#.WtokKKrrsoM
Kalispel


USGS 12395500 PEND OREILLE RIVER AT NEWPORT WA
Discharge, cubic feet per second, [(2)]
200000
100000
10000
2000
2010
2011
2012
2013
2014
2015
2016
2017
2018
Median daily statistic (87 years)
Discharge
Estimated discharge
Period of approved data
Period of provisional data
Graph courtesy of the U.S. Geological Survey


Pend Oreille River at ID-WA Border
TP (mg/L)
0.05
0.04
0.03
0.02
0.01
0
9
8.5
8
7.5
7
6.5
TP
pH
Oct-03
Apr-04
Oct-04
Apr-05
Oct-05
Apr-06
Oct-06
Apr-07
Oct-07
May-08
Nov-08
May-09
Nov-09
May-10
Nov-10
May-11
Nov-11
May-12
Nov-12
May-13
Nov-13
May-14
Nov-14
May-15
Nov-15
May-16
Kalispel


Pend Oreille River at Kalispel Boundary
TP (mg/L)
0.05
0.04
0.03
0.02
0.01
0
9
8.5
8
7.5
7
6.5
TP
pH
Mar-10
Jul-10
Nov-10
Mar-11
Jul-11
Nov-11
Mar-12
Jul-12
Nov-12
Mar-13
Jul-13
Nov-13
Mar-14
Jul-14
Nov-14
Mar-15
Jul-15
Nov-15
Mar-16
Jul-16
Nov-16
Mar-17
Jul-17
Kalispel

## Human-Caused Contribution to Primary Productivity and pH in the Pend Oreille River

- Changes in low-flow channel morphometry by reservoirs
  - Expanded shallow habitat for macrophyte colonization
  - Reduced velocities & increased residence time especially at @ low flow
- Warmer water promoting primary growth rate and season length especially in shallow portions of reservoirs
- Continuous input of nutrients from WWTPs with mixing throughout the water column (almost all in euphotic zone)
- Phytoplankton production promoted especially in critical flow
- Macrophytes providing enhanced growing media for epiphyton
- Critical flow velocities in reservoir less limiting to epiphytic accrual


## Future Nutrient Management in the Pend Oreille River

- Acknowledge existing degradation contributed to by nutrients within the Pend Oreille River especially during critical conditions – not average flows
- Develop and adopt protective in-stream nutrient targets with equitable levels of aquatic resource protection throughout the Pend Oreille Basin
- Begin developing nutrient control strategies for the impounded river down-stream of the Lake
- Implement the most cost effective strategies for nutrient reduction to begin a measurable reverse in nutrient loading from WWTPs and other sources

## - Thank You -

Questions?

# Lessons Learned in Establishing Nutrient Criteria

on the Pyramid Lake Paiute Reservation


Kameron Morgan
Water Quality Manager
Pyramid Lake Paiute Tribe
kmorgan@plpt.nsn.us
plptwq.org


*2018 Western Numeric Nutrient Criteria Workshop*

## Overview

- Pyramid Lake Reservation
- History of Water Quality Standards
- 2015 Review of WQ Standards (WQS)
  - Identify Stakeholders
  - Data Review
  - Revise Standards
  - Conduct Public Outreach
  - Conduct Public Hearing
- Lessons Learned
- Questions

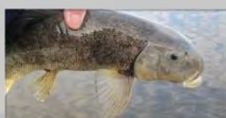
*Lower Truckee River Near Wadsworth, NV*

## Pyramid Lake Paiute Reservation

- 33 miles northeast of Reno, NV
- Reservation: 477,000 acres
- Surface waters
  - Pyramid Lake – 117,000 acres
  - Truckee River – last 31 miles
  - Streams
  - Springs and wetlands

## Pyramid Lake Paiute Reservation

- Pyramid Lake Paiute People – Kooyooe Tukuda, cui-ui eaters
- Home to the endangered cui-ui (*Chasmistes cujus*) and threatened Lahontan cutthroat trout (*Oncorhynchus clarkia henshawi*)



cui-ui
(*Chasmistes cujus*)

Lahontan cutthroat trout
(*Oncorhynchus clarkii henshawi*)

## History of Water Quality Standards (WQS)

- 1981: Pyramid Lake Water Quality Monitoring was established
- 1989-1993: Limnological study conducted by UC Davis
- 1990: Tribe received **T**reatment in the Similar manner **A**s **S**tates (TAS) of the CWA
- 2001: Council adopts Water Quality Control Plan
- 2008: EPA and Tribal Council approval of the Tribe's Water Quality Standards (WQS)
- 2015: EPA and Tribal Council approval of revised WQS

## Elements of WQ Standards

- Identify important cultural, community, and recreational uses of waters and establish criteria to protect beneficial uses
  - ***Primary Contact Ceremonial Use***, *aquaculture, Cold* ***Freshwater Habitat***, *Irrigation,* ***Riparian Habitat***, ***Sport Fishing***, *Water Quality Enhancement, etc.*
- Develop WQ criteria to protect beneficial uses
- Antidegradation Policy – Must conserve, maintain and protect the existing uses of a water body by maintaining high water quality

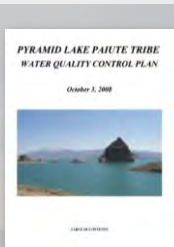
*Any surface waters of the Pyramid Lake Paiute Tribe whose quality is better than an applicable beneficial use standard of water quality as of date when those standards become effective must be maintained in their higher quality.*

## Steps to Developing WQS

1. Identified all waterbodies within the Reservation's boundaries that will require WQS
2. Designated beneficial uses for each waterbody or different portions of the same waterbody
3. Defined criteria by incorporating standards of the adjoining state and independently developed standards accounting for site-specific conditions

| Truckee River Water Quality Standards<br>Wadsworth Control Point | | | |
|---|---|---|---|
| **Parameter:** | **Standard:** | **Unit:** | **Notes:** |
| Dissolved Oxygen | Nov-Jun: ≥6.0 | mg/L | Single Value |
| | Jul-Oct: ≥5.0 | mg/L | Single Value |
| pH | 6.5-9.0 | pH | Single Value |
| Dissolved Reactive Phosphorous | ≤0.05 | mg/L | Annual Average |
| Nitrogen Species: | | | |
| Total Nitrogen | ≤0.75 | mg/L | Annual Average |
| Total Nitrogen | ≤1.2 | mg/L | Single Value |
| Nitrate | <2.0 | mg/L | Single Value |
| Nitrite | <0.04 | mg/L | Single Value |
| Total Ammonia | <CMC | | Salmonid fish present |
| | <CCC | | Fish early life stages present |
| Total Suspended Solids | ≤25 | mg/L | Annual Average |
| | ≤50 | mg/L | Single Value and <1000cfs |
| | ≤100 | mg/L | Single Value and >1000cfs |
| Temperature | Nov-Mar: ≤13 | °C | |
| | Apr-Jun: ≤14 | °C | |
| | Jul-Oct: ≤21 | °C | |
| Δ in Temperature | ≤2 | °C | Singe Value |
| Total Dissolved Solids | ≤310 | mg/L | Single Value |
| | ≤245 | mg/L | Annual Average |
| Turbidity | ≤10 | NTU | Single Value |

## Need for a Triennial Review

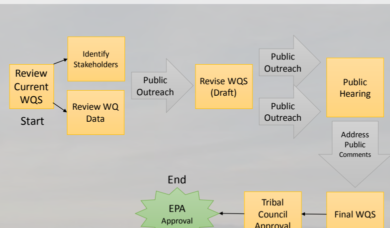

PYRAMID LAKE PAIUTE TRIBE
WATER QUALITY CONTROL PLAN

October 3, 2008

- Federal regulations require that states/tribes hold public hearings at least every three years to review applicable surface water quality standards and, as appropriate, adopt new or modified standards.

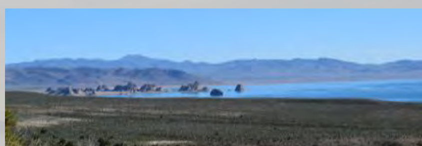
(40 CFR 131.20)

## Key Components of a Triennial Review



## Review Existing WQS and Supporting Documents

- Reviewed 2008 WQ Control Plan
- Reviewed Pyramid Lake Limnological Study
- Review EPA Recommended WQ Criteria
- Other historical and updated WQ documents



## Identify Stakeholders

Who are the stakeholders?

- Agriculture: Truckee Carson Irrigation District
- Urban: Truckee Meadows Water Association and Truckee Meadows Water Reclamation Facility (Reno, Sparks, Washoe County)
- Interstate: Town of Truckee (California)
- Government: NV Division of Environmental Protection (NDEP), EPA, Northern NV Water Planning Commission
- Reservation: Tribal community, departments, Tribal Council

## Identify Stakeholders

Who can provide technical assistance?

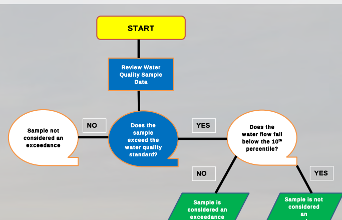
- DRI: Chris Fritsen and Jim Brock, Desert Research Institute
- Dan Mosley, Native Environmental Services
- EPA: Project Officer, Stephanie Wilson; Region 9 Water Division
- NDEP: Randy Pahl, Water Pollution Control

## Data Analysis

Gather field, nutrient and continuous WQ data from all sources:
- PLPT, USGS, NDEP, DRI, TMWRF

Things to consider:
- WQ criteria exemptions – high and low flow
- Phosphorus and nitrogen influence on dissolved oxygen contained in Limnotech Report
- Complexity of Truckee River management
  - Truckee River flows depend on discharges from upstream reservoirs and users
  - 2002 Cottonwood Recruitment Flows

## Data Analysis




## Revised Nutrient Criteria

**Ammonia (Pyramid Lake and Truckee River)**

**Proposed Change:** Adopt 2013 USEPA Ambient Water Quality Criteria for freshwater ammonia aquatic life.

**Justification:** Scientific recommendation from the USEPA.

**Dissolved Reactive Phosphorus (Truckee River)**

**Proposed Change:** Adopt a numeric water quality standard of from ≤0.05 mg/L to ≤0.022 mg/L.

**Justification:** State of Nevada equivalent

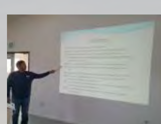
## Public Outreach

Meetings
- Introductory Meetings: Tribal Council, Tribal Communities (Wadsworth, Nixon, Sutcliffe)
- Public Workshops: Tribal Council, Tribal Communities, Fernley, Washoe County, Truckee
- Proposed Changes: Tribal Council, Northern NV Water Planning Commission

Public Comment
- May 26 – August 21, 2015
- Comments only accepted on proposed changes

## Public Hearing

Nixon, NV - August 6, 2015: Received testimony from public at large on proposed changes and recorded for public record

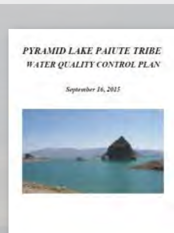


## Final Approval of WQS

Tribal Council approved revised standards on September 16, 2017, through Tribal Resolution PL 79-15

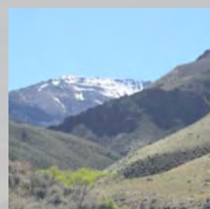
Submitted to EPA:
- Triennial review presentations
- Minutes from Public Hearing, meetings and workshops
- Public comments/answers on revised draft WQS
- Revised standards/Water Quality Control Plan
- Tribal Resolution

EPA Final Approval: December 23, 2015


PYRAMID LAKE PAIUTE TRIBE
WATER QUALITY CONTROL PLAN
September 16, 2015

## Lessons Learned

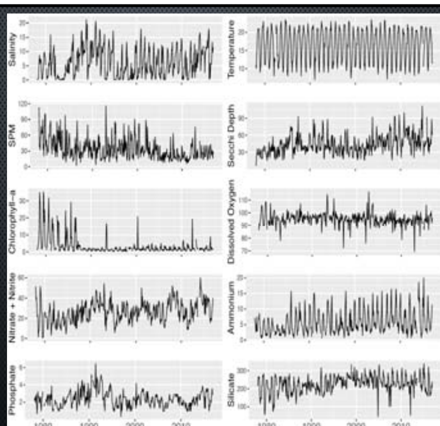
- Public outreach!
- You don't need to revise all of your WQS at once
- Review standards gradually, overtime
- Changes in monitoring
- Value of relationship with the State



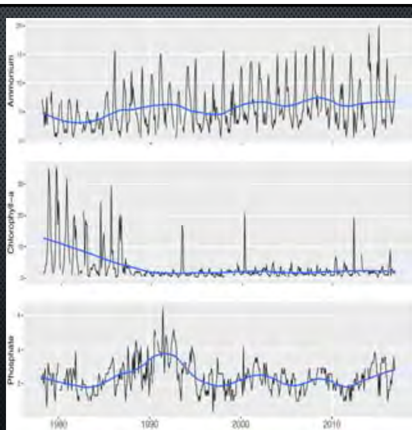
# PATTERNS AND PROCESSES OF WATER-QUALITY VARIABILITY

JIM CLOERN, USGS, MENLO PARK CA


THE OBSERVATIONS
1978-2016

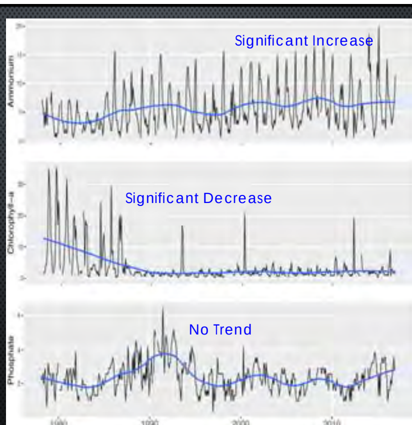


Smooth to Visualize Patterns



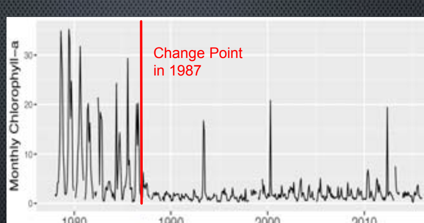

Lesson: patterns take many shapes

Trends with the Seasonal-Kendall Test



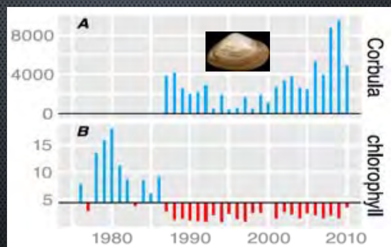

Lesson: Changes are Common (7 of 10)

Pettit Test



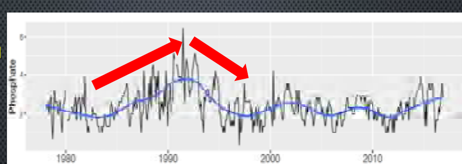

Lesson: Some changes are abrupt

INTRODUCTION OF THE NON-NATIVE CLAM *CORBULA AMURENSIS*




**LESSON:** CHANGES IN BIOLOGICAL COMMUNITIES HAVE EFFECTS ON WATER QUALITY

TRENDS ON SUBSETS OF THE DATA




**LESSON:** LONG-TERM TRENDS DON'T TELL THE WHOLE STORY

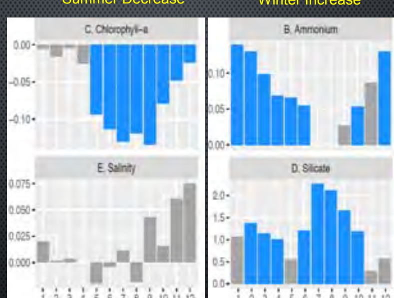
TRENDS BY MONTH

**LESSON:**

TRENDS ARE NOT UNIFORM ACROSS SEASONS

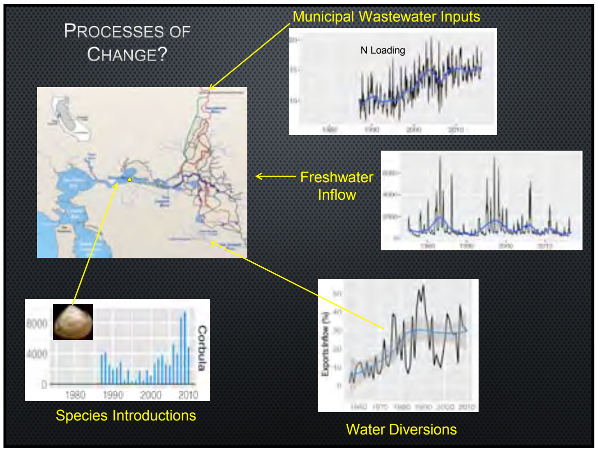
Summer Decrease

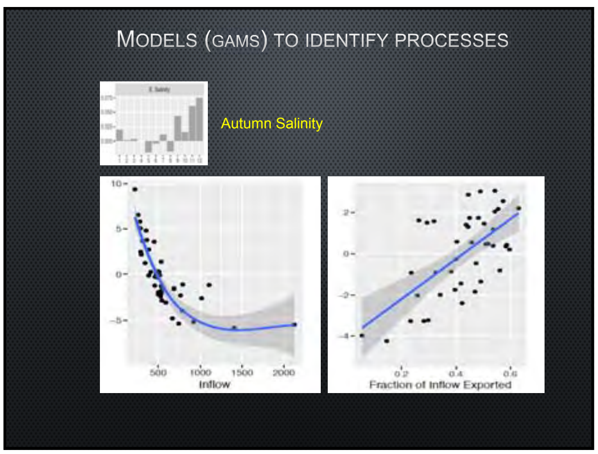
Winter Increase

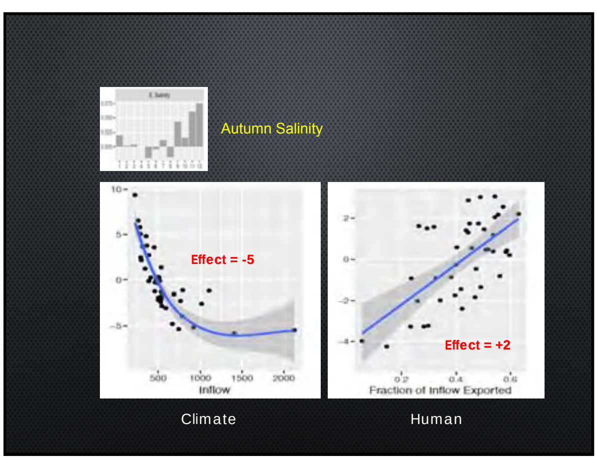


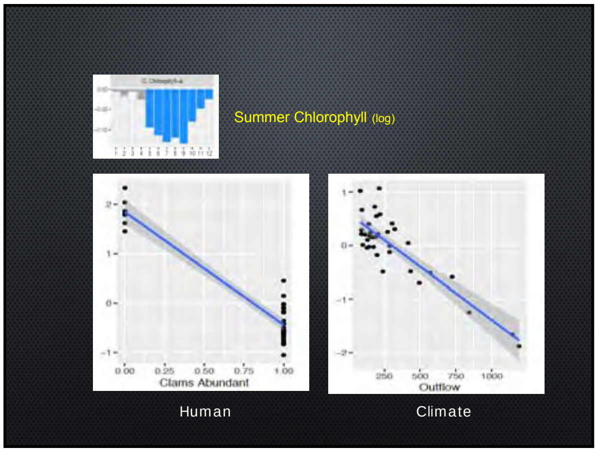

Autumn Increase

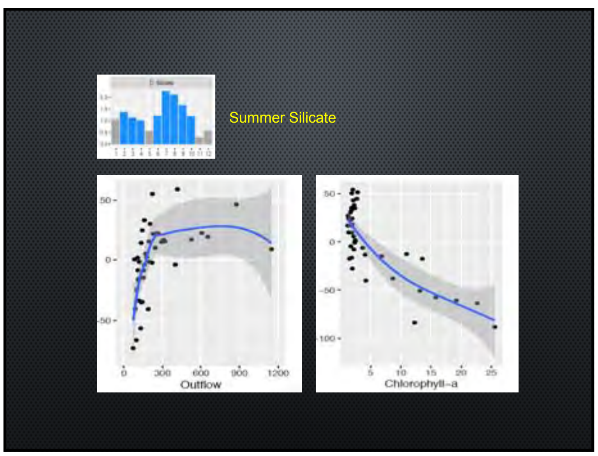
Summer Increase

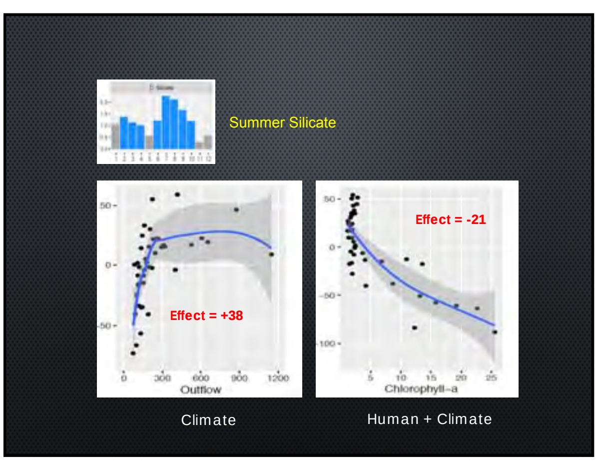

PROCESSES OF CHANGE?
Municipal Wastewater Inputs
N Loading
Freshwater Inflow
Cortuola
Species Introductions
Water Diversions

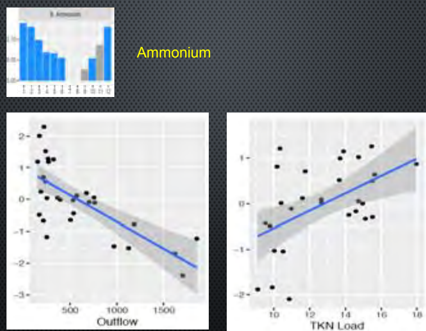

MODELS (GAMS) TO IDENTIFY PROCESSES
Autumn Salinity
Inflow
Fraction of Inflow Exported

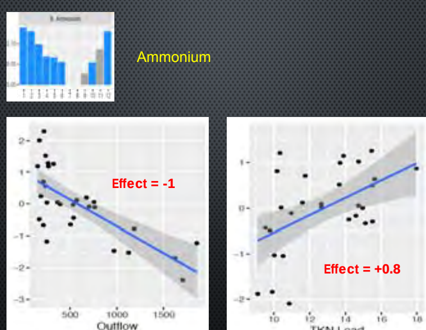

Autumn Salinity
Effect = -5
Inflow
Effect = +2
Fraction of Inflow Exported
Climate
Human


Summer Chlorophyll (log)
Clams Abundant
Outflow
Human
Climate


Summer Silicate
Outflow
Chlorophyll–a


Summer Silicate
Effect = +38
Effect = -21
Outflow
Chlorophyll–a
Climate
Human + Climate



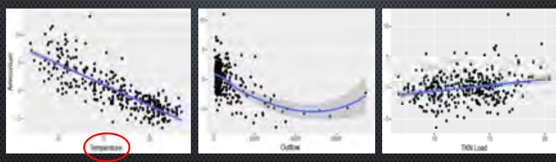

Climate Human

*We can Identify and Rank Importance of Processes*

| Annual Variability | Process 1 | Process 2 | $R^2$ |
|---|---|---|---|
| Salinity | - Inflow | + Export:Inflow | 0.84 |
| SPM | + Outflow | + Upstream SPM | 0.67 |
| Secchi Depth | - SPM | - Outflow | 0.90 |
| Chlorophyll-a | - Clam Abundance | - Outflow | 0.80 |
| Nitrate + Nitrite | - Outflow | - Chlorophyll-a | 0.63 |
| Ammonium | - Outflow | + Wastewater TKN Load | 0.59 |
| Silicate | + Outflow | - Chlorophyll-a | 0.65 |
| Phosphate | - Outflow | + Wastewater TP Load | 0.73 |

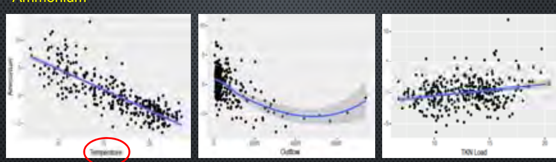
## Models of Monthly Variability

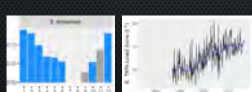
Ammonium



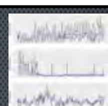

## Models of Monthly Variability

Ammonium



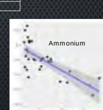
- **Estuaries are continually changing**
  - *Policies should be adaptive over the long term*



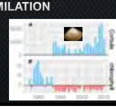
- **River inflow is a master variable**
  - *Policies should be seasonally adaptive*

| | | |
|---|---|---|
| Salinity | Inflow | |
| SPM | Outflow | |
| Secchi Depth | | Outflow |
| Chlorophyll-a | | Outflow |
| Nitrate + Nitrite | Outflow | |
| Ammonium | Outflow | |
| Silicate | Outflow | |
| Phosphate | Outflow | |

- **Inflow can be a nutrient source (Chesapeake) or diluent (SFB)**
  - *Policies should be ecosystem-specific*




- **Top-down control can regulate nutrient assimilation**
  - *Nutrients need to be managed in their ecosystem context*



WATER RESOURCES RESEARCH, VOL. 27, NO. 5, PAGES 803-813, MAY 1991

Selection of Methods for the Detection and Estimation of Trends in Water Quality

ROBERT M. HIRSCH, RICHARD B. ALEXANDER, AND RICHARD A. SMITH

*U.S. Geological Survey, Reston, Virginia*

WATER RESOURCES RESEARCH, VOL. 18, NO. 1, PAGES 107-121, FEBRUARY 1982

Techniques of Trend Analysis for Monthly Water Quality Data

ROBERT M. HIRSCH, JAMES R. SLACK, AND RICHARD A. SMITH

Nonparametric trend tests:

- Greater power (efficiency) of detecting trends in non-normal data
- Seasonal-Kendall removes effects of seasonal variability
- Trend slope is resistant to effects of extreme values